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Causal modelling procedures developed in economics and biology provide social scientists with powerful methodological tools that permit them to bridge the gap between theory and research. In this paper one type of causal modelling technique involving a structural set of equations that are recursive in form has been used to reanalyze the data from two empirical studies that have appeared in the literature. The paper demonstrates how models of this form broaden the scope of the usual regression analysis. (Author)

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CAUSAL MODELS IN EDUCATIONAL RESEARCH:

RECURSIVE MODELS

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ABSTRACT

Causal modelling procedures developed in economics and biology provide social scientists with powerful methodological tools that permit them to bridge the gap between theory and research. In this paper one type of causal modelling technique involving a structural set of equations that are recursive in form has been used to reanalyze the data from two empirical studies that have appeared in the literature. The paper demonstrates how models of this form broaden the scope of the usual regression analysis.

Blumer (1955, p.3) has pointed out that ideally:

> ...theory exercises compelling influence on research-setting problems, staking out objects and leading inquiry into asserted relations. In turn, findings of fact test theories, and in suggesting new problems invite the formulation of new proposals

Most social scientists would agree, however, that a hiatus exists between social theory and empirical research. In large part this gap results from the lack of articulation among the verbal language used to state social theories, the operational language that specifies how concepts are to be measured, and the mathematical language that permits the empirical verification of the theory (Blalock, 1964). Recent works by Stinchcombe (1968) and by Blalock (1969) address themselves to this problem and attempt to explicate the process by which social scientists can effectively reformulate verbal theories in terms of more rigorous mathematical models which can be empirically verified.

The logic of experimental design provides one approach to this problem and permits the scientist to isolate the separate effects of a number of independent variables on a dependent variable. Problems arise, however, in attempting to draw inferences from non-experimental data where a large number of outside factors influence the variables under consideration and their effects cannot be ruled out on the basis of randomization. Methodologies which allow causal inferences to be made in this instance have been developed in biology (Wright, 1934; 1954; 1960; Li, 1956) and economics (Wold and Jureen, 1953; Wold, 1954; Johnston, 1963; Goldberger, 1964) and have only recently been applied to the social sciences (Blalock, 1964; 1971; Duncan, 1966; Land, 1969).

The purpose of this paper is to demonstrate how these causal modelling procedures can be applied to theoretical models of interest to those involved in educational research.

CAUSAL INFERENCE PROCEDURES

Causal inference procedures begin with a statement of a verbal theory that makes explicit the relationships that are hypothesized among a set of variables as well as the causal sequence thought to exist among them. An example from Evans and Anderson (1972) involves the effect of achievement values on student achievement. Their earlier research as well as that of others suggests that student achievement is highly affected by the student's self-concept of his ability (Brookover and Thomas, 1964; Coopersmith, 1968). This factor is in turn affected by the student's world view, in particular whether or not he believes in the efficacy of manipulating his physical and social environment to his advantage (Kluckhohn, 1950). Value orientations, however, result largely from socialization practices such as achievement training and independence training that occur in the cultural setting of the home (Strodtbeck, 1958; McClelland, 1953). Finally, Elder (1962a; 1965) and Elder and Bowerman (1963) have demonstrated that these child-rearing practices vary with the family's socioeconomic and ethnic status as well as with the child's sex. Rosen (1959) also found achievement values to be highly related to ethnicity and social class.

These hypothetical causal relationships have been diagrammatically depicted in Figure 1. The path diagram indicates linear, additive relationships among the set of variables that are included in the model. All but

the first four variables are considered to be endogenous and as such to be completely determined by variables included in the model as well as by a residual variable. This residual variable represents the effects of all other variables not included in the model that cause variation in an endogenous variable. It is assumed that the residual variable is uncorrelated with the other variables that determine the endogenous variable.

FIGURE 1

The double headed arrows linking sex, father's education, language, and ethnicity indicate that these four variables are considered to be exogenous to the system. No attempt is made to account for variation in these variables since they are considered to be influenced by other variables outside of the system. Intercorrelations among these exogenous variables are shown in Figure 1.

Once the model has been formulated, a set of structural equations can be written. These structural equations are shown below. Each variable is in its standard form.

$$X_5 = p_{54}X_4 + p_{53}X_3 + p_{52}X_2 + p_{51}X_1 + p_{5a}R_a \qquad [1]$$

$$X_6 = p_{65}X_5 + p_{64}X_4 + p_{63}X_3 + p_{62}X_2 + p_{61}X_1 + p_{6b}R_b$$

$$X_7 = p_{76}X_6 + p_{75}X_5 + p_{74}X_4 + p_{73}X_3 + p_{72}X_2 + p_{71}X_1 + p_{7c}R_c$$

$$X_8 = p_{87}X_7 + p_{86}X_6 + p_{85}X_5 + p_{84}X_4 + p_{83}X_3 + p_{82}X_2 + p_{81}X_1 + p_{8d}R_d$$

$$X_9 = p_{98}X_8 + p_{97}X_7 + p_{96}X_6 + p_{95}X_5 + p_{94}X_4 + p_{93}X_3 + p_{92}X_2 + p_{91}X_1 + p_{9e}R_e$$

In the case of the model shown where there are no feedback loops or reciprocal causation between two variables, ordinary regression analysis can be used to estimate the parameters in each equation separately.[1] The path

coefficients p_{ij} which are shown alongside of each arrow in Figure 1 are standardized partial regression coefficients: For example, $p_{53} = \beta_{53.124}$ and $p_{64} = \beta_{64.1235}$. These path coefficients measure the proportion of the standard deviation of the dependent variable accounted for by an independent variable with the effects of all other variables that precede either of the two variables removed (Land, 1969). Path coefficents for the set of equations above are shown in Table 1. These estimates are based on data from a sample of 102 Anglo-American and Mexican-American junior high school students from a study conducted in a city in the southwest.[2]

TABLE 1

The structural equations permit the correlation between any two endogenous variables or between an endogenous and an exogenous variable shown in Table 2 to be expressed in terms of the paths leading to the two variables from antecedent variables as well as the direct path between them. For example

$$r_{63} = \Sigma X_3 X_6/N \qquad [2]$$

$$= \frac{1}{N}\Sigma X_3[p_{65}X_5 + p_{64}X_4 + p_{63}X_3 + p_{62}X_2 + p_{61}X_1 + p_{6b}R_b]$$

$$= p_{65}\Sigma X_5X_3/N + p_{64}\Sigma X_4X_3/N + p_{63}\Sigma X_3X_3/N + p_{62}\Sigma X_2X_3/N + p_{61}\Sigma X_1X_3/N$$

$$+ p_{6b}\Sigma R_bX_3/N$$

If we note that $\Sigma X_3X_3/N = r_{33} = 1$ and $\Sigma R_bX_3/N = r_{b3} = 0$, this reduces to

$$r_{63} = p_{65}r_{53} + p_{64}r_{43} + p_{63} + p_{62}r_{23} + p_{61}r_{13} \qquad [3]$$

We can expand r_{53} in a similar fashion giving

$$r_{63} = p_{63} + p_{65}p_{53} + p_{65}p_{54}r_{43} + p_{65}p_{52}r_{23} + p_{65}p_{51}r_{13} + p_{64}r_{43} + p_{62}r_{23} + p_{61}r_{13} \quad [4]$$

TABLE 2

The zero-order correlation r_{63} is defined as the total effect of X_3 on X_6. From equation [4] it can be seen that it is composed of a direct effect, p_{63}; an indirect effect, $p_{65}p_{53}$, since X_3 effects X_5 which in turn effects X_6; and joint effects (the remaining terms in equation [4]) due to the correlation of X_3 with the other exogenous variables in the model. When two endogenous variables such as X_5 and X_7 are involved, this last component of the correlation between the two variables is termed a spurious effect since it arises from the mutual correlation of the dependent and independent variables with other variables preceding them in the model.

Table 3 provides a breakdown of the total effect of each endogenous and exogenous variable included in the model on an achievement score into direct and indirect effects.[3]

TABLE 3

In a similar fashion a formula for the residual path coefficient can be derived from the structural equations. The formula is $p_{ia} = \sqrt{1-R^2}$ [5] where R^2 is the squared multiple correlation coefficient for a particular equation. As mentioned earlier this path coefficient measures the effect of all unmeasured variables not included in the model that cause variation in the endogenous variable.

ACHIEVEMENT VALUES AND ACHIEVEMENT

An examination of Table 3 is most revealing. Self-concept of ability has a large direct effect on achievement as hypothesized. If this variable increases by one standard deviation, achievement increases by four-tenths of a standard deviation, a rather substantial amount. While activism-mastery has a large zero-order correlation with achievement, most of this effect is spurious and is due to the fact that both measures are highly correlated with three of the four exogenous variables and with independence training. Nevertheless, this variable has an important indirect effect on achievement through its effect on self-concept. The path coefficient linking this value orientation to self-concept is .25. Self-concept is linked to achievement by a path coefficient of .42. The indirect effect of activism-mastery on achievement then is (.25) (.42) = .11. Apparently this value orientation has an important effect on achievement but not as generally thought. Instead this variable appears to effect the student's self-concept of ability which has been shown to have an important effect on achievement.

The effect of parental stress on achievement and independence training are direct but of opposite sign. While direct attempts by parents to encourage achievement appear to attenuate achievement, the effect of independence training on achievement appears to be positive. This suggests that families enhance their children's achievement in school by fostering self-reliance by granting them enough autonomy to make their own decisions and to accept responsibility for success or failure. This conclusion is similar to the findings of McClelland (1953) and Elder (1962b).

Ethnicity has small direct and indirect effects on achievement. Anglo-

American students out-perform their Mexican-American peers. Part of this differential can be accounted for by the greater confidence among the former group in their ability to master their physical and social environments.

Both the use of English in the home and father's education affect student achievement. An increase in either variable directly results in increased student achievement. There are indirect effects as well. In both instances, an increase in the exogenous variable results in an increase in independence training and self-concept of ability among students with an attendant positive effect on achievement.

Finally, sex has a small negative effect on achievement. Girls experience more independence training than boys resulting in higher achievement scores. This is partially offset by their lower self-concept scores, however.

It is interesting to note that the zero-order correlation between each of the exogenous variables and achievement, with the exception of sex, overestimates the true effects of these variables. This results from the high intercorrelations among the three variables. As a result, the joint effect in each case accounts for a large part of the total effect of each variable on achievement.

BUREAUCRACY AND THE IMPERSONAL TREATMENT OF STUDENTS

A second example is taken from Anderson's (1968) study of the effect of bureaucracy on public school teachers. A study by Gouldner (1954) and the writings of Merton (1957) suggest that bureaucratic rules may affect the personalities of individual members of an organization in such a way as to result in an impersonal attitude toward clients; in the case of the school, students. Organizations, however, differentially utilize rules to control

behavior of subordinates. In the schools, tenured teachers and the more experienced teachers are subject to fewer rules regarding instructional practices (Anderson, 1968).

This same study found bureaucratic rules and impersonal treatment of students to be more prevalent in large schools and in schools that enrolled large numbers of lower class students. Terrien and Mills (1955) in a study of California public school districts also found that bureaucracy, as measured by the proportion of personnel engaged in administrative activities, increased with the size of the organization. Moreover, the more experienced, tenured teachers, on the whole prefer to teach in schools that enroll the majority of their students from middle class families. Also female teachers and English teachers were found to make more of an attempt to personalize instruction than their colleagues. While both groups of teachers are more experienced on the whole than other teachers, they were found to be subject to a greater number of constraints in the form of instructional rules. This causal structure is depicted in Figure 2.

FIGURE 2

The structural equations have been omitted but they are of the same form as shown earlier. The parameters of these equations, shown in Table 4, were estimated from data obtained from 114 english and science teachers in the public schools of a large eastern metropolitan area.[4]

TABLE 4

Total effects or zero-order correlations shown in Table 5 have been partitioned into direct, indirect, and joint or spurious effects in Table 6.

TABLE 5

TABLE 6

Results of the analysis indicate that as hypothesized the degree of institutional control in the form of rules concerning classroom instruction effects the teacher's relationships with his students. As rules increase within a department, the teacher spends less time counseling individual students and adopts a more universalistic grading scheme, two of the components that make up the impersonality score.

Tenure appears to have a negative direct effect on impersonality. Tenured teachers make a greater effort to personalize their teaching. On the whole they spend more time with individual students and are more particularistic in their grading practices. This effect is not due to experience since the main effect of teaching experience on the impersonality score is through tenure. Tenured teachers may feel more secure in dealing with students and with their superiors since they are not as frequently supervised and can only be dismissed for cause. Also a selection process has occurred by this time in a teacher's career that may also account for their greater tendency to individualize instruction.

The teacher's sex also appears to affect the manner in which he deals with students. Male teachers on the whole are more impersonal in their treatment of students. Similarly the size of the school, as predicted, directly affects this variable. Teachers who are assigned to larger schools are more impersonal with students. Also larger schools are more bureaueratic with an attendant increase in impersonality. Such an effect may result in large part from the complexity of large schools offering several academic curricula

and providing a large number of extra-curricular activities for students. Other studies also suggest that it is complexity rather than size that accounts for increased bureaucracy (Bendix, 1956; Anderson and Warkov, 1961).

Interestingly enough, the socioeconomic composition of the school and the type of department in which the teacher works have no over all effect on the relationship established between teacher and student. In the first instance, while teachers of lower class students make more of an attempt to work with individual students, they are subject to more instructional rules than their colleagues which offsets the direct effect of school composition. Similarly fewer science teachers are tenured while at the same time they make more of an attempt to individual instruction than english teachers. As before direct and indirect effects offset one another.

SUMMARY

Causal modelling procedures that have been developed in economics (Wold, 1954; Wold and Jureen, 1953; Johnston, 1963; Goldberger, 1964) and biology (Wright, 1934, 1954, 1960; Li, 1953) provide powerful methodological tools for social scientists in their attempts to relate theory and research through the analysis of cross-sectional data (Blalock, 1964, 1969, 1971; Duncan, 1966; Land, 1969). These techniques provide a methodology whereby causal relationships among a set of variables hypothesized to be inter-related in a theoretical framework can be specified; mathematical equations which allow the prediction of the effects of changes in the value of any one variable on all other variables in the model can be written; the parameters of the model can be estimated from these equations; and the model can be empirically verified.

This paper has dealt with one type of causal model involving one-way causation. The structural equations in this instance are recursive and parameters of each equation can be separately estimated using ordinary least squares. This approach broadens the scope of simple regression analysis that treats a single dependent variable and a set of independent variables. While methods exist to estimate the parameters of structural models involving feedback and reciprocal causation under certain conditions (Johnston, 1963; Goldberger, 1964), these approaches have not been treated here, although several good applications to social science data exist in the literature (Duncan etal., 1968; Mason and Halter, 1968; Land, 1971).

Two empirical examples were discussed in order to illustrate causal inference procedures. However, the algorithms presented in this paper are applicable to a broad range of theoretical problems of interest to social scientists engaged in educational research.

NOTES

[1]Parameters of models that contain feedback loops or reciprocal causation under certain conditions can be estimated with techniques that have been developed in economics (Goldberger, 1964; Johnston, 1963). The recent applications of these estimation techniques are Duncan, etal. (1968) Mason and Halter (1968) and Land (1971).

[2]Details concerning the nature of the population and sample as well as the development of scales and indices are described in Evans (1969) and Anderson and Johnson (1971). For purposes of this paper sex was coded 0 = male, 1 = female; father's education was 0 = no school, 1 = less than 8 years, 2 = 8 years, 3 = 9-11 years, 4 = 12 years, 5 = post high school technical school, 6 = some college, 7 = college graduate; language usage was based on a factor score that indicated the amount of english spoken in the home; ethnicity was coded 0 = Mexican-American, 1 = Anglo-American; independence training was measured by a Guttman scale developed by Elder (1962b); factor scores for parental stress on achievement, activism-mastery, and self-concept were used; achievement was measured with the composite score on the Iowa test of basic skills.

[3]Anderson (1971) has developed an alternate computational scheme based on dynamic programming. His algorithm permits the computation of indirect effects. Joint or spurious effects for each variable in the model are then found by subtraction.

[4]This study is reported in detail in Anderson (1968). Impersonality scores were coded 0 = low, 1 = medium, 2 = high as were departmental rules scores; tenure was coded 0 = special substitute, 1 = probationary, 2 = tenured; teaching experience was coded from 1 to 5 with 5 representing 5 or more years of experience; sex was coded 0 = female, 1 = male; department was coded 0 = english, 1 = science; school SES was coded 0 = low, 1 = medium, 2 = high; school size was coded 0 = small, 1 = medium, 2 = large.

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Figure 1: Path Model Relating Achievement Values to Achievement: Mexican-American and Anglo-American Students Combined[a]

[a]Path coefficients and the corresponding arrows for values less than .10 have been omitted in order to simplify the diagram.

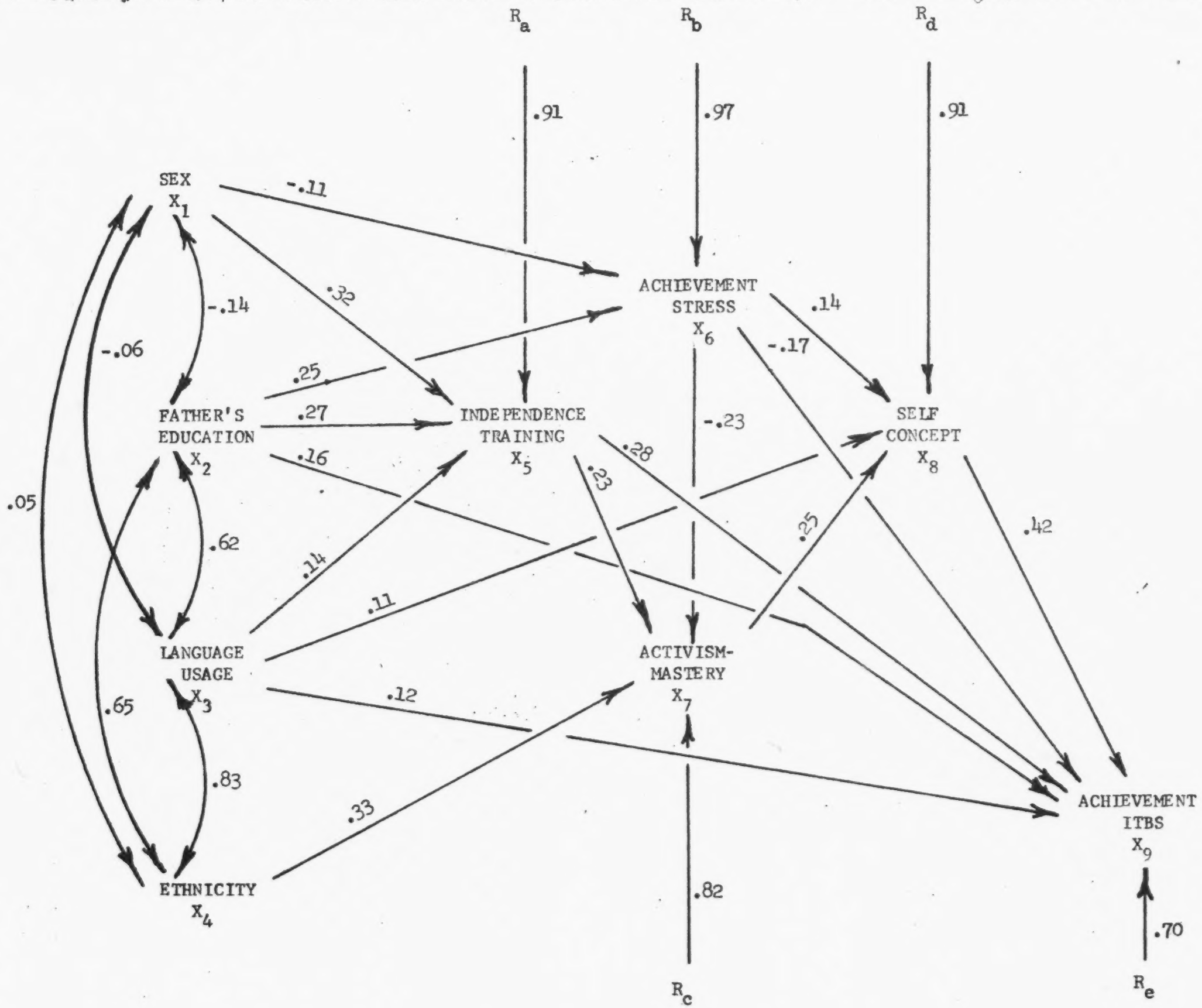
R_a
R_b
R_d
.91
.97
.91
SEX
X_1
-.11
-.14
-.06
.32
.25
.27
.16
.05
.62
.14
.11
.12
.65
.83
.33
.23
.28
.25
.42
ACHIEVEMENT
STRESS
X_6
.14
-.17
-.23
FATHER'S
EDUCATION
X_2
INDEPENDENCE
TRAINING
X_5
SELF
CONCEPT
X_8
LANGUAGE
USAGE
X_3
ACTIVISM-
MASTERY
X_7
ACHIEVEMENT
ITBS
X_9
ETHNICITY
X_4
.82
.70
R_c
R_e

Figure 2: Path Model Relating Bureaucratic Rules to Teacher's Impersonality Scores[a]

[a]Path coefficients and the corresponding arrows for values less than .10 have been omitted in order to simplify the diagram.

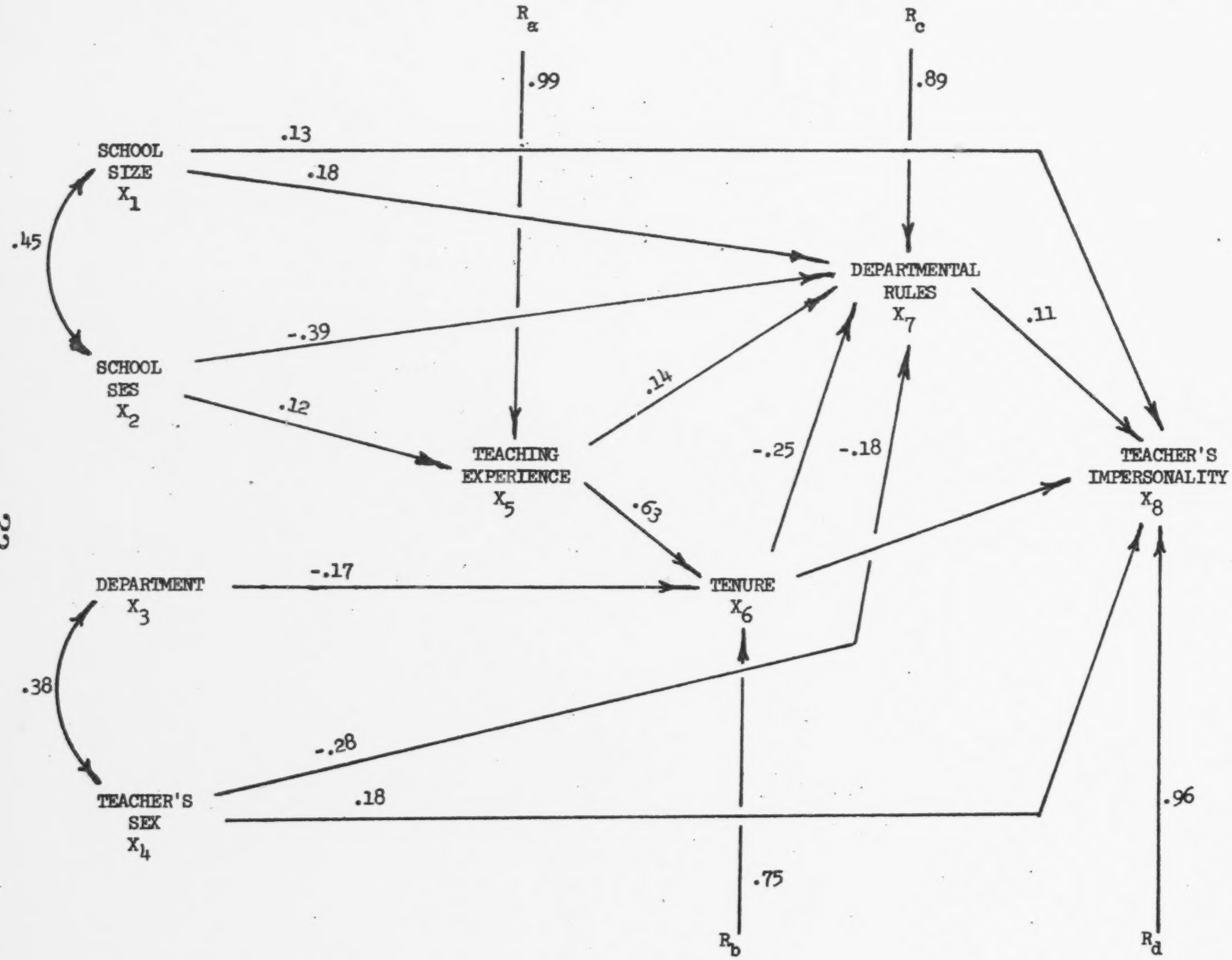
R_a
R_c
.99
.89
.13
SCHOOL SIZE X_1
.18
.45
DEPARTMENTAL RULES X_7
.11
-.39
SCHOOL SES X_2
.14
.12
TEACHING EXPERIENCE X_5
-.25
-.18
TEACHER'S IMPERSONALITY X_8
.63
-.17
DEPARTMENT X_3
TENURE X_6
.38
-.28
TEACHER'S SEX X_4
.18
.96
.75
R_b
R_d

TABLE 1

MULTIPLE CORRELATION COEFFICIENTS AND STANDARDIZED PARTIAL REGRESSION COEFFICIENTS, MEXICAN-AMERICAN AND ANGLO-AMERICAN STUDENTS COMBINED

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	MULTIPLE CORRELATION COEFFICIENT	STANDARDIZED PARTIAL REGRESSION COEFFICIENT
Achievement ITBS Score	Sex	.71	-.03
	Father's Education		.16
	Language Usage		.12
	Ethnicity		.09
	Independence Training		.23
	Parental Stress on Achievement		-.17
	Activism-Mastery		.02
	Self-Concept		.42
Self-Concept	Sex	.40	-.08
	Father's Education		.07
	Language Usage		.11
	Ethnicity		.06
	Independence Training		.01
	Parental Stress on Achievement		.14
	Activism-Mastery		.25
Activism-Mastery	Sex	.57	.03
	Father's Education		-.05
	Language Usage		.08
	Ethnicity		.33
	Independence Training		.28
	Parental Stress on Achievement		-.23
Parental Stress on Achievement	Sex	.24	-.11
	Father's Education		.25
	Language Usage		-.08
	Ethnicity		-.09
	Independence Training		.02
Independence Training	Sex	.41	.32
	Father's Education		.27
	Language Usage		.14
	Ethnicity		-.08

TABLE 2

INTERCORRELATION MATRIX
MEXICAN-AMERICAN AND ANGLO-AMERICAN STUDENTS COMBINED
(N = 102)

VARIABLE	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1.000	-.14	-.06	.05	.26	-.14	.15	-.07	.01
X_2		1.000	.62	.65	.26	.17	.24	.27	.44
X_3			1.000	.83	.22	.02	.38	.30	.47
X_4				1.000	.23	.01	.43	.30	.47
X_5					1.000	.02	.37	.14	.37
X_6						1.000	-.24	.10	-.09
X_7							1.000	.29	.38
X_8								1.000	.54
X_9									1.000
Mean	.510	2.922	.020	1.324	6.284	-.012	-.023	-.019	45.520
Standard Deviation	.502	2.349	.973	.470	2.550	.946	.842	.875	11.780

X_1 - Sex

X_2 - Father's Education

X_3 - Language Usage

X_4 - Ethnicity

X_5 - Independence Training

X_6 - Parental Stress on Achievement

X_7 - Activism-Mastery

X_8 - Self-Concept

X_9 - Achievement ITBS Composite Score

TABLE 3

CONTRIBUTION OF VARIABLES TO ACHIEVEMENT
MEXICAN-AMERICAN AND ANGLO-AMERICAN STUDENTS COMBINED

VARIABLE	TOTAL EFFECT	DIRECT EFFECT	INDIRECT EFFECT THROUGH OTHER VARIABLES	JOINT OR SPURIOUS EFFECTS
Self-Concept	.54	.42	---	.12
Activism-Mastery	.38	.02	.11	.25
Parental Stress on Achievement	-.09	-.17	.03	.05
Independence Training	.37	.23	.04	.10
Ethnicity	.47	.09	.06	.32
Language Use	.47	.12	.10	.25
Father's Education	.44	.16	.06	.22
Sex	.01	-.03	.07	-.03

TABLE 4

MULTIPLE CORRELATIONS AND STANDARDIZED PARTIAL REGRESSION COEFFICIENTS

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	MULTIPLE CORRELATION COEFFICIENT	STANDARDIZED PARTIAL REGRESSION COEFFICIENT
Impersonality	Rules	.29	.11
	Tenure		-.18
	Experience		.06
	Sex		.18
	Department		-.04
	Socioeconomic Status		.06
	School Size		.13
Rules	Tenure	.46	-.25
	Experience		.14
	Sex		-.28
	Department		-.01
	Socioeconomic Status		-.39
	School Size		.18
Tenure	Experience	.66	.63
	Sex		.04
	Department		-.17
	Socioeconomic Status		-.07
	School Size		.00
Experience	Sex	.15	-.07
	Department		-.05
	Socioeconomic Status		.12
	School Size		-.03

TABLE 5

INTERCORRELATION MATRIX

TEACHERS

N=114

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	1.00	.45	.07	.02	.02	-.03	.01	.16
x_2		1.00	.03	-.07	.11	-.01	-.28	.08
x_3			1.00	.38	-.07	-.21	-.07	.06
x_4				1.00	-.10	-.08	-.25	.15
x_5					1.00	.64	-.03	-.07
x_6						1.00	-.13	-.17
x_7							1.00	.08
x_8								1.00
Mean	1.54	1.13	.39	.30	3.97	1.56	1.12	.76
Standard Deviation	.67	.65	.49	.46	1.45	.72	.64	.79

x_1 - School Size

x_2 - School Socioeconomic Status

x_3 - Department

x_4 - Teacher's Sex

x_5 - Teaching Experience

x_6 - Teacher's Tenure Status

x_7 - Departmental Rules Score

x_8 - Teacher's Impersonality Score

TABLE 6

CONTRIBUTION OF VARIABLES TO
THE TEACHER'S IMPERSONALITY SCORE

VARIABLE	TOTAL EFFECT	DIRECT EFFECT	INDIRECT EFFECT THROUGH OTHER VARIABLES	JOINT OR SPURIOUS EFFECT
Rules	.08	.11	--	-.03
Tenure	-.17	-.18	-.03	.04
Experience	-.07	.06	-.11	-.02
Sex	.15	.18	-.04	.01
Department	.06	-.04	.04	.06
Socioeconomic Status	.08	.06	-.04	.06
School Size	.16	.13	.02	.01